RC building Seismic Reinforcement Method Utilizing Steel Portal Frames without Braces

[0001]

TECHNICAL FIELD

The present invention relates to a seismic reinforcement method for a reinforced concrete (RC) building utilizing rigid steel frames without braces and, more particularly, to a method for stiffening a reinforced concrete building of low seismic resistance capacity by fixing steel portal frames to the external surfaces around openings such as windows of the building.

[0002]

BACKGROUND

A reinforced concrete building of low seismic resistance capacity is often stiffened by enlarging the sectional area of columns thereof. For example, the existing RC-column 50 in Fig. 12(a) is covered with additional reinforced concrete 51 as shown in Fig. 12(b) or is wound by steel plates 52 as shown in Fig. 12(c). Such methods are only applicable to a fully naked structure like a bridge pier.

[0003]

A brace is another means for reinforcing structures. Such a reinforcement method is also applicable to schoolhouses, apartment houses and/or office buildings having columns which can not be accessed on all sides, i.e., the brace is used to stiffen the RC portal frame using columns and beams bridged over said columns.

[0004]

A portal frame is introduced into an existing RC-structure since it is impossible to directly bridge a brace over an RC-column and an RC-beam thereof. Fig.13(a) shows an example of a steel portal frame 54 with braces 53 buried in the wall and Fig. 13(b) is an example of a steel portal frame 55 fixed to the outside of the columns and beams. These days, this type of steel portal frame with braces has been typical of the reinforcement used because of the short time for reinforcement

completion but also because it does not increase building weight. In particular, a method utilizing steel portal frames applied to the outside of an existing building makes it unnecessary to remove windows and walls around the windows thereof, and is increasingly used to remarkably shorten the period for completing the building reinforcement.

[0005]

JP11-193639A1 discloses a method using steel portal frames applied to the external surfaces of columns and beams so that the reinforcement may be carried out quickly and easily. A brace makes such a portal frame for reinforcement more stable, i.e., the brace of the steel portal frame combined with RC-columns and RC-beams consequently reinforces the RC-structure.

[0006]

Such a method can also reinforce the building while leaving inhabitants therein. The frame however is made of wide flange sections which introduce a sharp change in appearance to the old apartment house, which were often originally monotonous. Coloring the frames sometimes changes the original appearance of the house. Further, use of a tube-in-tube type brace (see e.g., JP11-193570A1) having an outer diameter much smaller than the members of the frame provides the building with a lilting impression based on the small appearance of the brace.

[0007]

It has been recognized that the steel portal frame without braces never contributes to the reinforcement of an RC-structure because the frame is more deformative under the RC-column forces and it is required to introduce braces into the steel portal frame. The understanding that a brace is indispensable for the portal frame reinforcing the RC-structure has already been widely and deeply accepted by builders.

[0008]

A portal frame with braces need not provide the frame members with high rigidity, so that the sectional area of the members can be rather small. On the other hand, it is important to improve the characteristic of braces to be introduced into the frame, therefore, research and development for the improvement of the bracing has continued.

[0009]

The above illustrates that the frame is merely an auxiliary member as a toehold for fixing a brace to a building. It has been believed that the steel portal frame being more deformative than the RC-structure will not reinforce the RC-structure, and therefore, a brace is always necessary to stiffen the frame.

[0010]

SUMMARY OF THE INVENTION

The steel portal frame with braces, where the stress acting on the brace is transmitted to the columns and beams of its own frame, has the rigidity in the horizontal direction remarkably higher than, e.g., 50 to 100 times as high as that of the steel rigid frame. The horizontal load acting on the RC-structure 56 deforms mainly RC-column 57 as shown in Fig. 14(a) since the beams of the building are generally locked by the building floor slabs.

[0011]

As shown in Fig. 13(b) the steel portal frame 55 fixed to the RC-structure 56, having higher rigidity than the steel frame, results in being loaded with much larger horizontal forces than that of the RC-structure. Fig. 15 illustrates that the part except the cross of column and beam, e.g., a spot fixing a gusset-plate 59a on the steel beam 58, gathers horizontal forces transmitted to the RC-beam 60. In this case, the distribution of stress transmitted from the steel portal frame 55 to the RC-beam 60 is shown by arrows B departing from gusset-plate 59a, resulting in applying an extremely heavy load on stud dowels, etc., mentioned below.

[0012]

The steel portal frame 55 is united to the RC-column 57 and the RC-beam 60 with cement mortar or concrete placed into the space between them accommodating chemical anchors and/or stud dowels. The concrete formed in the space mentioned above results in being overloaded because of the large difference of the allowable strength in the horizontal direction based on the rigidity in the horizontal direction of the steel column 61 of the portal frame 55 reinforced by a brace 53 from that of the RC-column 57 of the RC-structure 56. In other words, the effect of reinforcement due to the steel portal frames is gradually lowered with the increased damage to the concrete in the connecting space caused by the overload against the chemical anchors, etc.

[0013]

The braces fixed close to windows for the purpose of reinforcing an apartment house spoil the view from the windows even if the braces are industrial refined products. The circumstance that even an inhabitant who wants to reinforce the apartment house does not always want windows with braces in his own living space often delays the seismic reinforcement of the apartment house as there is a conflict between the interest of those inhabitants who are forced to have windows with braces and other inhabitants who are not.

[0014]

The introduction of a brace into the steel portal frame requires the use of a gusset-plate 59, as there must be plenty of steel for the reinforcement of the steel beam 58 to which the gusset-plate 59a is fixed compared with the quantity spent for the reinforcement of the crossing of column and beam holding the gusset-plate 59b. The span of the old building requiring the seismic reinforcement is generally so short that small steel portal frames for the building are often used. This means that the amount of the secondary steel, i.e., gusset-plates, stiffening plates, etc., against the amount of steel used for columns and beams of the portal frames will rise to uneconomic levels.

[0015]

The object of the invention is to provide a seismic reinforcement method for RC buildings utilizing steel portal frames without braces in order to solve the problems mentioned above; the first is to obtain a trim appearance having windows without braces, though the steel portal frames are applied to the outside of an existing building, the second is to maintain the combination of steel portal frame and RC-structure as long as possible under the horizontal load repeated during a big earthquake, thereby, increasing the strength in the horizontal direction based on the reinforcement effect due to the steel portal frame before the building is destroyed so that the collapse of the building in the early stage of the earthquake may be avoided even when it is a big earthquake and the third is to save amount of steel used for secondary reinforcement to successfully achieve a simplified construction and reduced reinforcement cost.

[0016]

[BRIEF DESCRIPTION OF DRAWINGS]

Fig. 1 is a schematic outside view of a part of an RC building to which the seismic reinforcement method utilizing steel portal frames made of wide flange sections without braces is applied.

[0017]

Fig. 2 shows schematic views of the composition fixing a portal frame made of wide flange sections to the outside of building; Fig. 2(a) shows a sectional view of the example using a welded product of H-shape in cross section and Fig. 2(b) shows a sectional view of the example using a steel column having high bending rigidity.

[0018]

Fig. 3 shows diagrams of deformation in the horizontal direction of column vs. horizontal load acted thereon; Fig. 3(a) shows load vs. displacement in the case that ordinary steel is used for wide flange section column and Fig. 3(b) shows load vs. displacement in the case that steel of low yield point is used for wide flange section column.

[0019]

Fig. 4 are plan views of existing apartment houses having living spaces partitioned by earthquake resisting walls; Fig. 4(a) shows an example of seismic reinforcement utilizing steel portal frames without braces against the horizontal force in the horizontal direction thereof and Fig. 4(b) shows an example of seismic reinforcement utilizing T-section against the horizontal force in the lateral direction thereof.

[0020]

Fig. 5 is a plan view of the calculating model according to the seismic reinforcement method utilizing steel portal frames without braces.

[0021]

Fig. 6 is a diagram showing load vs. displacement in the horizontal direction of an RC-column and wide flange section column having different bending rigidity from that of an RC-column.

[0022]

Fig. 7 are plan views of combination situating the wide flange section column close to existing RC-structure; Fig. 7(a) shows an example of RC-column covered with the wide flange section column, Fig. 7(b) shows an example of the wide flange

section column facing an external surface only of RC-column and Fig. 7(c) shows an example of the chemical anchors fixed to wide flange section column.

[0023]

Fig. 8 is an elevation view showing the joining part of wide flange section columns vertically in series arranged on a point of contraflexure.

[0024]

Fig. 9 is a plan view showing a composition fixing T-section to the outer surface of web of the wide flange section column.

[0025]

Fig. 10 is an elevation view showing a seismic reinforcement composition fixing T-sections to both sides of living space.

[0026]

Fig. 11(a) shows a detailed cross sectional composition of the end of interior RC-beam taking along line A-A in (c), Fig. 11(b) shows a view taking along line B-B in (c) and Fig. 11(c) shows a sectional view of the interior RC-beam supporting floor slab.

[0027]

Fig. 12 shows cross sections of a reinforced column, Fig. 12(a) shows original RC-column, Fig. 12(b) shows RC-column covered with additional reinforced concrete and Fig. 12(c) shows RC-column wound by steel plates.

[0028]

Fig. 13(a) shows a schematic view of steel portal frame buried in the wall and Fig. 13(b) shows a schematic view of steel portal frame fixed to the external surfaces of columns and beams.

[0029]

Fig. 14 shows schematic views of the deformation of existing RC-structure and steel portal frame fixed thereto under the horizontal load, Fig. 14(a) shows the behavior of RC-column and RC-beam in RC-structure and Fig. 14(b) shows the behavior of steel column deforming together with existing RC-column.

[0030]

Fig. 15 are schematic views of the transmission of stress in RC-structure reinforced by steel portal frames with braces.

[0031]

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a seismic reinforcement method for RC buildings utilizing a steel frame for stiffening an existing RC-structure by fixing the steel frame to the outside of the reinforced concrete structure which has openings like windows Referring to Fig. 1, the steel frame is a portal frame 3 made of wide flange sections without braces, which is fixed to the outside of an existing RC-column 5 extending in the vertical direction and to the outside of an existing RC-beam 8 extending in the horizontal direction. The wide flange section column 4 of the portal frame is fixed to the existing RC-column 5 and is assigned a bending rigidity roughly equivalent to that of the existing RC-column 5, being much less than that of a steel portal frame with braces, thereby not only reducing the stress additionally occurring at the connecting part 9 (see Fig. 2) between the existing RC-column and the wide flange section column by deforming the column 4 similarly to the existing RC-column 5 under the horizontal load transmitted from existing RC-beam 8 and/or wide flange section beam 6 during an earthquake, but also increasing the resultant strength in the horizontal direction of the combination 10 of the RC-column and wide flange section column by decreasing the deformation of the RC-column 5 after yielding so as to equalize the range of quasi-elastic deformation of said combination to that of elastic deformation of the column 4.

[0032]

As shown in Fig. 2(a), the wide flange section column 4 is preferably a welded product of H-shape in cross section. Web 4w is arranged close to the RC-column. Referring to Fig. 2(b), the column 4 is fixed to the RC-column 5 is accompanied by tie hoops 22 welded on the outer surface of the web 4w of the column Bending rigidity thereof is increased by placing cement mortar or concrete 24 into the space accommodating said tie hoops engaged with vertical bars 23.

[0033]

The wide flange section column 4 is made of steel of low yield point, reducing yield bending strength only without reducing the bending rigidity thereof, thereby reducing the response stress thereof in a big earthquake through the plasticization hastened by yielding the combination of the RC-column and the wide flange section column at the bending strength of approximately 3 to 4 times as strong as the

existing RC-column 5.

[0034]

Referring to Fig. 9, the wide flange section column 4 is stiffened by a T-section 25, taking the form of T in plan view, extending over all the stories, the leg 25a of which is welded on the outer surface of the web 4w of the column at its tip, three-dimensionally reinforcing the building by the alignment of the T-sections with the interior RC-beams 26A or earthquake resisting walls 26B not only extending perpendicularly to the external walls but being united to the existing RC-columns 5 which are reinforced by the wide flange section columns 4.

[0035]

The T-section 25A projects outside as wide as a verandah 27 of each story.

[0036]

As shown in Fig. 11(c) the interior RC-beams 26A or RC-beams over the existing earthquake resisting walls have additional beams made of high strength fluidized concrete 30 or cement mortar at both sides thereof. This not only obtains the desired bending moment based on the post-tension generated by unbonded prestressing steel bars 31 buried in the additional beams, but also attains the strength required in the horizontal direction of said beams.

[0037]

The seismic reinforcement method for RC buildings utilizing steel portal frames without braces according to the present invention is disclosed below in detail referring to some examples. The invention is a method for stiffening an existing RC-structure by fixing a steel frame to the outside of a reinforced concrete structure with openings like windows. Utilizing such reinforcement, a building may be reinforced while leaving inhabitants therein. What is notable in the invention is that the wide flange section column of the steel frame is assigned a bending rigidity roughly equivalent to that of an RC-column of the reinforced concrete structure.

[0038]

The steel frame column is equipped with a bending rigidity of -70% to +200% as high as that of an RC-column. Accordingly, the inventive reinforcement never compares to a steel portal frames with braces which has a huge bending rigidity of 50 to 100 times as high as that of an RC-column. This means that the bending rigidity of a wide flange section column fixed to an existing RC-column is of the

same order as that of the RC-column, being much less than that of a steel portal frame with braces.

[0039]

Fig. 1 shows an outside view of a part of one RC building story with windows 2 in the RC-structure 1 to which a portal frame 3 made of wide flange sections without braces mentioned above is fixed. The steel column 4 of portal frame 3 is combined with an existing RC-column 5 extending in the vertical direction along the external wall of the building and the steel beam 6 thereof is combined with an existing RC-beam 8 extending from the RC-column 5 to the right and/or left sides thereof, supporting the load including the vertical load caused by the weight of the external walls 7, etc.

[0040]

The steel portal frame 3 composed of wide flange section column 4 and wide flange section beam 6 has no braces, and is not designed to have the high rigidity corresponding to that of a steel portal frame reinforced by braces. The bending rigidity assigned to column 4 fixed to the existing RC-column 5 is selected to be roughly equal to that of the existing RC-column. It is noticeable that the steel column deformation is approximately equivalent to the deformation of the RC-column (being much more deformative than the frame with braces) as applied to the reinforcement of the RC-structure.

[0041]

In brief, the wide flange section column 4 results in deforming similarly to the existing RC-column 5 under the horizontal load transmitted from existing RC-beam 8 and/or wide flange section beam 6 in a big earthquake. The stress additionally occurred at the connecting part 9 shown in Fig. 2(a) between the existing RC-column and wide flange section column is remarkably small in response to the decrease of difference of the bending deformation of the existing RC-column 5 from that of column 4.

[0042]

In addition, since the deformation of RC-column 5 is restrained after yielding at the displacement in the horizontal direction shown by .$_{RC}$ in Fig. 3(a), the combination 10 of the RC-column and the wide flange section column 4 results in the possession of a broad range S of quasi-elastic deformation indicated by the line

being slightly bent, though being regarded as approximately straight, up to the deformation corresponding to the elastic deformation $._H$ in the horizontal direction of the wide flange section column, furthermore, providing a great increase of strength in the horizontal direction thereof as described below.

[0043]

Since the yield bending stress of steel column 4 is much bigger than that of RC-column 5 in the case that bending rigidity of the steel column is of the same order as that of the RC-column, the seismic resistance capacity of the combination of steel portal frame and RC-structure results in an increase of at least 3 to 4 times as large as the RC-structure alone. The reinforcement according to the present invention not only generates much higher seismic resistance capacity than the existing reinforcement achieving the strength in the horizontal direction at most twice as strong as the existing RC-column, but keeps original openings without braces. The cross-section of the steel portal frame made of wide flange sections, being more narrow than the width of columns and beams of existing reinforced concrete, simply blends well with the appearance of an existing building, thereby making the reinforcement of such buildings much more practical.

[0044]

Referring to Fig. 2, the portal frame 3 made of wide flange sections is combined with RC-columns 5 and RC-beams 8 by the use of chemical anchors 11, stud dowels 12, spiral hoops 13 and high strength non-shrink mortar 14. The existing building under the horizontal load mainly deforms the columns because the beams are always locked by floor slabs as described in Fig. 14(a).

[0045]

The bending rigidity of the wide flange section column 4 being roughly equivalent to that of RC-column 5 under the condition that wide flange section beam 6 is united to RC-beam 8 makes column 4 deform similar to RC-column 5 as shown in Fig. 14(b) so that the difference of deformation of the former from that of the latter may be very little, consequently, reducing the stress transmitted through chemical anchors and/or stud dowels in the connecting part 9 (see Fig. 2) to a minimum.

[0046]

The big additional stress in the connecting part will not occur even under the

horizontal load based on an earthquake, accordingly, the horizontal loads are smoothly transmitted from the steel portal frames to the RC-frames and vice versa. Such a steel rigid frame provides stud dowel, etc. with the uniform load due to the shearing force transmitted throughout all of the beams, being different from the frame with braces described in the Prior Art.

[0047]

The steel portal frame 3 deforms similarly to the RC-frame 1 as shown in Fig. 14(b) though the former is originally more deformative than the latter, simplifying the composition of the connecting part as well as facilitating the rationalization of the overall reinforcement, from design to construction. The inventor's have determined that the deformation of existing RC-column comes to much the same as that of the wide flange section column provided that the bending rigidity of column 4 fixed to existing RC-column 5 is assigned to -70% to +200%, preferably -60% to +150%, as high as that of the existing RC-column.

[0048]

Although today's builders believe that braces are indispensable for the reinforcement of RC-structure by reason that deformative steel frames will not stiffen a reinforced concrete building, the present invention dares to remove braces from the steel portal frame. A tube-in-tube type brace is still an eyesore even if it has a smart appearance. Needless to say, the steel portal frame without braces according to the invention is acceptable for seismic reinforcement, consequently, promoting the seismic reinforcement of buildings which have not yet been reinforced.

[0049]

The steel portal frame without braces requires no gusset-plates for braces. Since braces, being smart in appearance, are often connected to frames by pin joints, the gusset-plates as joints are inevitably required to be thick, besides, the web of the wide flange section column must be reinforced by stiffening plates, etc., for the sake of fixing the gusset-plates thereto. Adopting no braces favorably results in requiring no reinforcements such as stiffening plates.

[0050]

Furthermore, many small steel portal frames for seismic reinforcement are used for an old building, especially, for out-of-date apartment houses 15 of short

span shown in plan view of Fig. 4. Applying the prior art portal frame with braces to the building to be reinforced requires a high percentage of the space, being not negligible, taken up by auxiliary reinforcements mentioned above against wide flange section as main reinforcements.

[0051]

Though the portal frame with braces can not hide the existence of secondary reinforcements applied to over all the frame, the portal frame without braces itself becomes inconspicuous due to few auxiliary reinforcements, approximately equal to zero, and it may look as if the building was not reinforced.

[0052]

The present invention makes the combination of RC-structure and steel portal frame behave in one united body without acting unfavorably to force applied on the connecting part of the combination, therefore, the range of elastic deformation becomes large by decreasing the deformation of the existing RC-column, and besides, the strength in the horizontal direction of the reinforced building greatly increases under the contribution of steel of high original strength. Such a steel portal frame needs braces no longer. The reinforcement of the RC-structure without braces has not been achieved until the knowledge mentioned above was discovered by the inventor.

[0053]

The support for the wide flange section column having bending rigidity equal to that of an existing RC-column being practical is discussed below with the explanation of increasing the strength of the combination according to an example calculation based on the model 16 of Fig. 5. Provided the cross section of the RC-column 5 is 60 centimeters square, the geometrical moment of inertia thereof is given as follows:

1. $I = 60 \times 60^3 / 12 = 1,080,000 \text{ cm}^4$.

[0054]

It is well-known in the design for earthquake-proof buildings that 70% of original geometrical moment I of inertia of reinforced concrete is available even at the allowable strength (at the limit of elasticity) in spite of occurrence of little cracks thereon, accordingly, I_{RC} is obtained below:

2. $I_{RC} = 1,080,000 \text{ cm}^4 \times 0.7 = 756,000 \text{ cm}^4$.

[0055]

The yield bending strength (yield moment) of an RC-column based on the geometrical moment of inertia is given below: Assuming that the total sectional area a_t of reinforcing bars is 17.02 cm^2 and allowable unit stress f_t thereof is 2.4 $tons/cm^2$, the distance between centers of tension and compression resultants j and the yield bending strength ${}_{RC}M_y$ are obtained as follows:

3. $j = 7d / 8 = 7 / 8 \quad (60 - 5.0) = 48.1$ cm,

therefore, ${}_{RC}M_y = a_t \cdot f_t \cdot j$

$= 17.02 \times 2.4 \times 48.1 = 19.65$ t.m.

[0056]

Next, provided the wide flange section column 4 is 40 centimeters wide and 40 centimeters deep, thickness t_f of its flange = 2.5 centimeters and thickness t_w of its web = 1.6 centimeters, the geometrical moment I_S thereof is as follows:

4. $I_S = 20^2 \times 2.5 \times 40 \times 2 + 1.6 \times 40^3 / 12$

$= 88{,}533\ cm^4$.

[0057]

Since the ratio of Young's modulus of steel to concrete is approximately 10, the geometrical moment ${}_{eq}I_S$ of inertia equivalent to reinforced concrete column is written as follows:

5. ${}_{eq}I_S = 88{,}533 \times 10 = 885{,}330\ cm^4$.

[0058]

This is approximately equal to $I_{RC} = 756{,}000\ cm^4$ calculated above.

[0059]

Section modulus Z_S, yield bending strength ${}_SM_y$ and ${}_SM_y/{}_{RC}M_y$ of wide flange section column 4 are respectively as follows:

6. $Z_S = 88{,}533 / 20 = 4{,}427\ cm^3$,

${}_SM_y = 4{,}427 \times 2.4 = 106.2$ t.m

and ${}_SM_y / {}_{RC}M_y = 106.2 / 19.65 = 5.4$.

[0060]

The strength in the horizontal direction of the combination may theoretically increase by 5.4 shown above against 1.0 of RC-column to 6.4 times in the case that stud dowels and chemical anchors are enough for transmitting the strength of the wide flange section column.

[0061]

Since Young's modulus of steel is about 10 times as large as that of concrete, the example calculation illustrates that a steel column of bending rigidity similar to the reinforced concrete is easily obtainable. Although the nature of reinforced concrete is different from that of steel, their behavior is much the same within the range of elasticity. Since the yield bending strength of wide flange section column is higher than that of RC-column under the condition that the bending rigidity is the same among them, both the combination of RC-column and wide flange section column basically results in being elastic.

[0062]

As shown in Fig. 3(a) the strength in the horizontal direction of a wide flange section column 4 made of ordinary steel is 5.6 times, at least keeping elastic, as strong as that of the RC-column 5 being regarded as 1. The steel is loaded up to deformation $._H$ in the horizontal direction corresponding to the limit of elasticity, whereby, the growth of damage of reinforced concrete remains within the deformation in the horizontal direction. If the yield bending strength of wide flange section column is low, the load on the reinforced concrete column increases accompanying with damage based on large deformation. According to the present invention the steel portal frame contributes to decrease the damage of reinforced concrete column also after yielding.

[0063]

Oppositely, the elastic behavior of the wide flange section delays the advance in collapse of reinforced concrete. Though an existing reinforced concrete structure absorbs seismic energy in compensation for being damaged, the reinforcement according to the present invention not only remarkably decreases the damage to the reinforced concrete but lightens the repair works thereafter.

[0064]

As described above, the bending rigidity of the wide flange section column fixed to the existing RC-column is assigned to -70% to +200% as high as that of the existing RC-column, i.e., 0.3 to 2.0 times. Above all, the bending rigidity of wide flange section column had better be bigger than that of existing RC-column. In consideration of using steel, 150% (= 1.5 times) is enough to restrain the occurrence of cracks in the reinforced concrete after the RC-column 5 is beyond its

elastic limit.

[0065]

On the other hand, approaching the absolute value of % to 100 on the negative side means not to reinforce the building, therefore, the value should be selected within at least -70%. Because even the steel having bending rigidity of only 30% of that of existing RC-column is expected enough for reinforcing an existing slightly superannuated RC-structure. Any steel having much higher bending strength than the reinforced concrete greatly contributes to reinforce RC-columns, accordingly, transmitting the load to the base of the building due to the decrease of damage to the reinforced concrete as well as restraining the instability of thebuilding in the early stage of an earthquake.

[0066]

Use of the steel of low yield point ($._y$ = 1.5t/cm^2) for the column 4 reduces the yield bending strength thereof only to about 1/2 as shown in Fig. 3(b) without reduction of the bending rigidity thereof. According to the example calculated above the yield moment of the wide flange section column may be reduced from 5.4 times to 2.7 times as large as RC-column 5.

[0067]

Thus, the wide flange section column can yield at the yield bending strength of 2 to 4 times as strong as existing RC-column, not only promoting the plasticization of the wide flange section column at a big earthquake but reducing the response stress against the earthquake. In other words, the absorption of seismic energy due to large plastic deformation against the excessive force greatly restrains an instantaneous collapse without quick reduction of strength of the wide flange section column.

[0068]

Because of the excessively high yield bending strength of wide flange section column, there occurs some problems in the toughness-type reinforcement for high-rise buildings in spite of almost no problems in the strength-type reinforcement applied to middle- and/or low-rise buildings. It is significant to reduce the yield bending strength for removing the problems described before.

[0069]

Fig. 3 shows diagrams of load vs. displacement in the horizontal direction

under the condition that the bending rigidity of the wide flange section column is the same as that of an RC-column. The column 4 made of ordinary steel elastically behaves in a broad range as shown in Fig.3(a) needs to largely deform before the plasticization thereof based on a big earthquake.

[0070]

On the other hand, Fig.3(b) teaches us that wide flange section column begins to yield at the horizontal strength of about 3 times as strong as that of existing RC-column so that the wide flange section column may be plasticized in relatively early stage during a big earthquake. It is well-known that moderate plasticization of wide flange section column remarkably reduces the response against the earthquake. Accordingly, small response stress facilitates the design for not only the base of the building but the whole structure thereof to support the economical design.

[0071]

Selecting the bending strength of wide flange section column equivalent to that of reinforced concrete column is the basis of the present invention as explained above, then, giving rational composition to the connecting part. Fig. 6 is a diagram of load vs. displacement in the horizontal direction of RC-column 5 accompanying with the column 4 having different bending rigidity from that of RC-column, being drawn correspondingly to Fig. 3. In this case a combination of RC-column and wide flange section column will not be formed, accordingly, RC-column and wide flange section column deform independently. Therefore, the double-dotted chain line of N made by piling load vs. displacement of RC-column with that of wide flange section column, being drawn similarly to the broken lines in Fig. 3, is not obtainable in practice.

[0072]

The idea of the present invention is expanded below: Fig. 7 shows the examples in which the column 4 is fixed to the chemical anchors 11 driven into the RC-column 5. Fig.7(a), which is an embodiment of wide flange section column covering the whole of the projecting part of RC-column 5, and Fig.7(b) is another of column 4 facing a flat external surface only of RC-column. Thus, the wide flange section column is arranged so close to reinforced concrete that only the narrow space 9A between existing RC-column and wide flange section requires high

strength non-shrink mortar.

[0073]

Arranging the column 4 close to RC-column 5 requires no stud dowels. The steel rigid frame structure can decrease the consumption of secondary materials in compensation for the increase of main supporting materials in the case that the bending rigidity in the lateral (horizontal) direction of wide flange section column equivalent to that of reinforced concrete column can be obtained in spite of the reinforcement due to the wide flange section column slightly projecting from the external surface of the reinforced concrete. The simplification of steel portal frame contributes to not only the decrease of construction materials but to a great reduction of total cost for the reinforcement.

[0074]

Incidentally, the position for joining columns 4 vertically disposed in series to each other in the direction along the axis of column is assigned to the point where the bending moment M_5 of RC-column 5 in Fig. 8 is equal to 0 (being called a point of contraflexure). Because the middle point between upper beam 6u and lower beam 6d gives the bending moment of $M_4 = 0$ to column 4 as well as to RC-column 5. The steel plate 17 welded on the lower end of column 4 is joined to the steel plate 17 welded on the upper end of another column 4 by high tension bolts 18.

[0075]

Referring to Fig. 7, a hole 19 having an annular clearance 19a shown in Fig.7(c) allows for an inaccurate position of chemical anchor 11 against the wide flange section column 4 which is formed in the web 4w of column so as to fix the column 4 to chemical anchors driven into the RC-column 5. Welding the washer 21 used for a nut 20, locks the column 4 to the RC-column, on the web 4w to prevent the column 4 from moving.

[0076]

Both the wide flange rolled section with web 4W drawn by double-dotted chain lines in Fig. 2(a) and the welded product consisting of three long steel plates are available for any portal frame 3 explained above. The latter with the web 4w optionally designed taking into consideration the position and/or size thereof may advantageously provide products made out of a standardized rolled section.

[0077]

Though the standardized products of rolled section with wide flange are used in general on the ground of mass-production, welded products of H-shape in cross section are greatly available if the web can be designed so as to obtain columns of bending rigidity equivalent to that of RC-column 5. The web 4w close to the RC-column as shown in Fig. 2(a) makes a narrow space 9A between a wide flange section column and RC-column, decreasing the consumption of expensive high strength non-shrink mortar 14.

[0078]

A short distance between wide flange section column 4 and RC-column 5 is preferable for increasing not only strength but the bending rigidity of the connecting part as well as for aligning the web of wide flange section column with the web 6w of wide flange section beam 6, therefore, transmitting the horizontal force to other wide flange section without unfavorable shearing force and/or moment. In the case that the bending rigidity of wide flange section column is insufficient it can be increased not only by welding tie hoops 22 engaged with vertical bars 23 on the outer surface of web 4w of the wide flange section column as shown in Fig. 2(b) but by placing cement mortar or concrete 24 over them.

[0079]

The reinforcement mentioned above is applied to the building being loaded by the horizontal force in the direction of x-axis shown in Fig. 4(a). However, the old buildings to be reinforced often have small rooms divided by a wall extending in the direction of the y-axis. It is impossible to remove earthquake resisting walls for the purpose of enlarging the rooms as far as interior RC-beams or the walls are designed so as to resist the horizontal force in the lateral direction, i.e., in the direction of the y-axis.

[0080]

Increasing the number of earthquake resisting walls and/or the thickness of existing walls to reinforce the lateral direction of a building reduces the living space. According to the present invention, T-sections 25, taking the form of T in plan view, are arranged so as to extend over all the stories along the outer surface of the web 4w of the wide flange section column 4 as shown in Fig. 9. The leg 25a of T-section is welded on the wide flange section column 4 so that the T-section is aligned with an interior RC-beam 26A and/or earthquake resisting wall 26B extending

perpendicularly to the external wall and being united to existing RC-column 5.

[0081]

Such T-section 25 provides the building with seismic reinforced columns forming an H in the lateral direction (in the direction of y-axis in Fig. 4(a)) because T-section 25 is united to the web 4w of wide flange section column 4. Both wide flange section column 4 itself being originally seismic reinforced column in the directions of right and/or left sides (in the direction of x-axis) and T-section 25 extending from the first story to the top story together achieve three-dimensional reinforcement, i.e., in the directions of x, y and z-axes of building. T-section 25 is fixed not only to the front surface but to rear surface of building as shown in Fig. 4(b) if necessary.

[0082]

The verandah spreading in series on each story provides the apartment house with space for reinforcing in the lateral direction thereof, then, utilizing the whole width of verandahs at the boundaries of neighboring houses. As shown in Fig. 4(b) the leg of T-section 25A is projected up to the handrail 27a (see also Fig. 9) on the line extended from the earthquake resisting wall, etc., by equalizing the length of leg 25a of T-section 25A to the width of verandah 27.

[0083]

In such a case both interior RC-beam 26A and earthquake resisting wall 26B should be reinforced as well as RC-column 5 combined with wide flange section column 4 on its external surface. Fig. 10 shows an example of living space 28 on one story, to not only the front side (see the left-hand side in the drawing) but rear side (see the right-hand side in the drawing) of which T-sections 25 are fixed. In this case the interior RC-beams 26A supporting floor slab 29 may be reinforced as shown in Fig. 11(c).

[0084]

Fig. 11(a) and (b) show the sectional views taking along line A-A and line B-B in Fig.11(c) thereof, respectively. Not only placing high strength fluidized concrete 30 or mortar on both sides of interior RC-beams 26A as shown in Fig.11(c) but generating post-tension in interior RC-beams by unbonded prestressed steel bars 31 buried in additional beams after curing the cement which provide the interior RC-beams 26A with desirable bending moment at their ends, resulting in attaining

the strength required in the horizontal direction of the beams. Such reinforcement enables removal of a part of the existing earthquake resisting walls for the purpose of enlarging the living space.

[0085]

According to the present invention, the wide flange section column fixed to existing RC-column is assigned a bending rigidity roughly equivalent to that of an existing RC-column so that one column deforms similarly to another, thereby reducing the additional stress occurred by the difference of the deformation of the RC-column from that of the wide flange section column in the connecting space faced thereto, and besides, remarkably decreasing the force transmitted through chemical anchors, etc.

[0086]

The instantaneous collapse of buildings during a big earthquake can be favorably avoided since the increase of strength in the horizontal direction based on the reinforcement due to steel portal frame before the collapse of the building keeps the combination of steel portal frame and RC-structure as long as possible. In addition, the amount of damage to the RC-column which should have yielded is restrained before the yield of wide flange section since the range of deformation due to elastic behavior of wide flange section column is wider than that of RC-column. Thus, not only the damage of RC-structure is decreased but the repair works thereafter is lessened due to delaying the absorption of seismic energy while avoiding collapse of the reinforced concrete structure.

[0087]

Non-use of braces keeps the original view from windows and use of a portal frame made of wide flange sections being narrower than the width of existing columns and beams hardly changes the appearance of building. All of inhabitants in an apartment house and tenants in an office building may easily agree with the seismic reinforcement structure out of self-interest, therefore, accelerating the reinforcement process.

[0088]

In the case of connecting a brace to a gusset-plate via a pin joint the gusset-plate is required to be rather thick. On the other hand, the steel portal frame without braces according to the invention need not use such a gusset-plate itself,

resulting in no reinforcement for the web of wide flange section beam. The removal of the steel materials secondarily used at a high rate for reinforcing old buildings being short in span promotes an inexpensive reinforcement operation.

[0089]

Arranging the web of wide flange section column close to RC-column facilitates to approximately equalize the bending rigidity thereof to that of RC-column. A narrow connecting part enables the alignment of the web of wide flange section column with the web of wide flange section beam having a cross section smaller than the wide flange section column, resulting in the transmission of horizontal force in high efficiency on the portal frame made of wide flange sections.

[0090]

The narrower the connecting part is, the shorter the distance for transmitting force so as not to apply excessive force on the connecting part, resulting in saving very expensive high strength non-shrink mortar and the secondary materials, e.g., anchors, etc. Accordingly, not only the simplification of the connecting part but decrease the costs for construction are attainable through the reduction of the reinforcement materials and the rationalization of the reinforcement structure.

[0091]

Both welding tie hoops engaged with main reinforcements on the outer surface of web of the wide flange section column and placing cement mortar or concrete over them increase the bending rigidity of the wide flange section column so that it may become approximately equivalent to that of RC-column even if the wide flange section column results in having low bending rigidity by reason of arranging the web thereof close to RC-column.

[0092]

Assigning wide flange section column to the steel of low yield point reduces the yield bending strength only, without reduction of the bending rigidity, yielding the wide flange section column at the bending strength of approximately 2 to 4 times as strong as the existing RC-column, consequently, the response stress is reduced by the plasticization of columns during a big earthquake.

[0093]

Both welding the end of leg of T-section on the outer surface of the web of the columns wide flange section and extending T-section all over the stories together

achieve the complete reinforcement of three axes of x, y and z, i.e., reinforcement in the horizontal direction of the external walls of the building, in the lateral direction perpendicular to the external walls and in the vertical direction of the external walls.

[0094]

Projecting a T-section as wide as the verandah of each house more strongly reinforces the building in the lateral direction thereof by utilizing the space of the verandah.

[0095]

The additional beam formed at both sides of the existing RC-beam connected to earthquake resisting wall, which is made of high strength fluidized concrete or cement mortar and unbonded prestressed steel bars under post-tensioning, provides the ends of reinforced beam with the desirable bending moment, largely increasing the horizontal strength in the lateral direction perpendicular to the external walls of the building.